

CONCLUSIONS

The Orbital Debris Capture experiment exposed $\sim 0.6 \text{ m}^2$ of SiO_2 -based aerogel for ~ 18 months on the Mir Station, providing a significant opportunity to evaluate the performance of this low-density, highly porous material for the capture of hypervelocity particles. This report summarizes optical studies of the impact features on ODC and provides examples of compositional analyses of individual projectile residues that were extracted from the collectors.

The highly porous, delicate aerogel medium superbly survived the launch and retrieval environment of Shuttle, as well as relatively long-term exposure in LEO. Therefore, it is a suitable material for a variety of missions engaged in the collection of either man-made debris or natural cosmic dust, such as the Stardust Mission to comet Wild 2.

Two distinct classes of hypervelocity impact features in aerogel were observed: slender, carrot-shaped tracks and substantially stubby, if not hemispherical pits. Features of intermediate morphologies between these dominant end-members suggest the presence of a morphologic continuum and of an evolutionary sequence from deep tracks to hemispherical pits. The absence of impactor residue, combined with the presence of distinctly glazed and translucent walls for most pits suggests that they formed – as a group – at higher impact velocities than the slender and very deep tracks, which are characterized by the needle like stylus, and a largely unmolten projectile remnant. Thus, we propose a velocity dependent continuum between deep tracks and shallow pits.

This interpretation suggests that the soft capture of hypervelocity particles in LEO is velocity limited. The specific threshold velocity beyond which the soft capture fails is poorly known, yet it is undoubtedly higher for aerogel than it is for all traditional, non-porous collectors. The fact that many superbly preserved and unmolten residues of both man-made and natural dust particles were recovered from aerogel and subjected to SEM and TEM analysis demonstrates that aerogel is a superb capture medium for most particles in LEO. Its dynamic range, although limited at the high-velocity end, is unsurpassed. It is simply unrealistic to expect any single material or capture method to operate successfully over the entire range of initial impact conditions represented by man-made and natural particles in LEO.

A third class of ODC impact features relates to low-velocity encounters with co-orbiting waste-materials, either liquid or solid, that result from the periodic venting of Shuttle's waste-water tank. On a particle frequency basis, such materials dominate those ODC surfaces that nominally pointed in the forward direction of Mir's orbital motion. While the collisional hazard seems minor due to the low-encounter velocities, the high frequency of such events may adversely affect critical components, especially optical quality surfaces.

We measured the relative frequency of track, pits, and shallow depressions for the two collector surfaces of ODC, yet these measurements are difficult to interpret in detail, largely because of poorly known pointing directions of these surfaces relative to Mir's velocity vector. Indeed, some of the observations suggest highly variable exposure geometries to the degree that the substantial differences in mean-encounter velocity and particle flux expected from a non-spinning spacecraft (*e.g.*, Zook, 1991) are simply absent on ODC. This includes the distribution of track lengths (Figure 33) which should be velocity sensitive and, therefore, differ between Tray 1 and Tray 2. Furthermore, the observation of modestly fewer tracks on Tray 1 than on Tray 2 (Table 1 or Figure 36) is inconsistent with prolonged exposures into forward- and

rearward-facing directions on an otherwise stationary platform. Mir's attitude must have been highly variable throughout the entire exposure period of ODC, as verified by the pinhole camera of PMPD (Kinard *et al.*, 1998).

Prominently clustered tracks and spatially isolated features of similar size and orientation on Tray 2 demonstrate the presence of debris clouds and the production of sizable populations of impact features caused by secondary impacts on spacecraft. Such clouds may have distinctly heterogeneous mass distribution and contain particles of variable sizes. In this specific case a natural impactor encountered either some Mir structure at very shallow incidence, or it penetrated some thin membrane, such that only projectile fragments contributed to the secondary particle swarm.

In conclusion, although the optical analysis and sample preparation for detailed compositional analysis via SEM-EDS or TEM methods are more time consuming than for non-porous media, this apparent disadvantage is far outweighed by the ability to preserve and trap unmolten residues for most hypervelocity particles in LEO. Aerogel is unquestionably a most superior capture medium and the best that is presently available. Unfortunately, neither conventional, non-porous collectors nor aerogel yield reliable dynamic data for individual particles, including chronological information of collisional events. Such dynamic and chronologic data are ultimately needed to understand the hypervelocity environment in LEO. Active instruments should be developed that measure the mass and trajectories of individual particles that, when combined with aerogel collectors, would provide unambiguous evidence to associate specific particles with either man-made sources and events, or with astrophysical sources, respectively (Zolensky, 1994).

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